Effects of Cochlear Implants on Children’s Reading and Academic Achievement

Marc Marschark
National Technical Institute for the Deaf–Rochester Institute of Technology

Cathy Rhoten
Western Pennsylvania School for the Deaf

Megan Fabich
New York School for the Deaf

This article presents a critical analysis of empirical studies assessing literacy and other domains of academic achievement among children with cochlear implants. A variety of recent studies have demonstrated benefits to hearing, language, and speech from implants, leading to assumptions that early implantation and longer periods of implant should be associated with higher reading and academic achievement. This review, however, reveals that although there are clear benefits of cochlear implantation to achievement in young deaf children, empirical results have been somewhat variable. Examination of the literature with regard to reading achievement suggests that the lack of consistent findings might be the result of frequent failures to control potentially confounding variables such as age of implantation, language skills prior to implantation, reading ability prior to implantation, and consistency of implant use. Studies of academic achievement beyond reading are relatively rare, and the extent to which performance in such domains is mediated by reading abilities or directly influenced by hearing, language, and speech remains unclear. Considerations of methodological shortcomings in existing research as well as theoretical and practical questions yet to be addressed provide direction for future research.

This article reviews the available evidence concerning the effects of pediatric cochlear implantation on the development of reading skills and academic achievement among deaf children. Literature reviews of this sort usually serve as introductions to empirical studies or as syntheses of evidence intended to support particular theoretical or philosophical positions. Neither of those situations is the case here. Rather, this article came about after the authors obtained two sets of empirical findings, studies initiated for very different purposes, which contradicted some generally accepted assumptions about the impact of cochlear implants on deaf children’s academic achievement.

One of the investigations was conducted at the Western Pennsylvania School for the Deaf (WPSD). Like other schools for the deaf, WPSD has seen its enrollment of children with implants increase steadily; in 2006, children with implants accounted for approximately 20% of its total enrollment. Since 2002, WPSD has tracked the academic progress of its students with implants in order to determine how well they are able to serve those children (Rhoten & Marschark, 2003, 2006). Each student with an implant has been matched with a student without an implant on the basis of birth date; gender; and enrollment in academic, transition, or applied studies programs. Students have been compared on the basis of their scores on the Stanford Achievement Test, 9th Edition (SAT9), and the Pennsylvania System of School Assessment (PSSA). The SAT9 includes subtests for language, mathematics problem solving, mathematics procedures, and reading comprehension. The PSSA includes subtests for mathematics, reading, and writing. The results are easily summarized: In none of the 4 years evaluated has there...
been any significant difference between the implant group and the matched comparison group on any of the seven subtests. What trends have been observed are just as likely to favor the nonimplanted group as the implanted group. Further, a 2005 analysis including 17 children with implants and their matched peers indicated no significant correlations between achievement and either length of time with an implant or age at implantation (see below).

The second investigation was an examination of deaf college students’ learning/academic achievement as it related to a variety of demographic and communication variables. Fabich (2005) reanalyzed data available from a series of experiments concerning classroom learning via sign language interpreting (see Marschark, Sapere, Convertino, & Seewagen, 2005, for a review). The experiments included 509 deaf students (with hearing comparison groups) enrolled at Rochester Institute of Technology (RIT), either in the National Technical Institute for the Deaf or in one of RIT’s seven other colleges. Experiments involved interpreted lectures provided by RIT faculty members on science-related topics. Learning was evaluated using multiple-choice tests designed in collaboration with the instructors. In one analysis, Fabich examined relations of cochlear implants and learning among 35 deaf students with implants and 35 randomly selected students with hearing aids. No significant difference in learning was observed. In a second analysis, Fabich examined nine entrance and placement test scores available for deaf students enrolled at RIT during the 2004–2005 academic years. Scores were available for 83 students identified as using cochlear implants, and they were compared to 71 randomly selected peers with hearing aids. No significant differences were observed on any of the tests.

Although lack of power may explain the WPSD findings, it is unlikely to be an explanation for the failure to observe differences in the RIT data. Implicit in both studies, however, was the assumption that deaf students with implants should be performing at a higher level than peers without implants. In order to determine the validity of that assumption, the following review was undertaken. In addition to an examination of the literature with regard to academic achievement in general, special attention was devoted to research concerning the development of reading skills of children with implants. In part, this focus not only reflects the ongoing challenge faced by deaf students in acquiring literacy skills comparable to their hearing peers (Marschark, 2007; Traxler, 2000) but also mirrors the concentration of empirical studies on the issue in the scientific literature.

The initial gathering of references for this review included all the relevant investigations that could be identified through academic and lay search sites, including those that are most frequently cited in secondary sources. The review covers primarily published (peer reviewed) research, although several other relevant studies are cited. Papers that failed to provide sufficient methodological or statistical information to fully evaluate their findings were considered, but these largely have been omitted unless they are of particular importance. Given the considerable heterogeneity observed among deaf children across a variety of domains, studies involving small samples were included only when key information concerning participant characteristics was provided.

Cochlear Implants and the Development of Reading Skills by Deaf Children

With the increasing number of children receiving cochlear implants and related improvements in hearing, language, and speech, there has been an expectation that enhanced phonemic awareness and phonological processing skills will result in better reading abilities among those children relative to peers without implants (e.g., Geers, 2002; Johnson & Goswami, 2005; Nicholas & Geers, 2006; see Spencer & Marschark, 2003, for a review). Several large-scale projects conducted at major implant centers in the United States and the United Kingdom have been most visible in providing evidence on this issue, but other important investigations have been reported as well.

“Implant Camp” Studies

A series of studies conducted by Geers (2002, 2003, 2004) took advantage of a summer camp designed to allow testing of large numbers of children with cochlear implants. These studies reported outcomes from 8- to 9-year-old children, all of whom had
received cochlear implants by age 5 years. Geers (2002) reported data on 136 children, tested 4–6 years after cochlear implantation. The Reading Recognition and Reading Comprehension subtests from the Peabody Individual Achievement Test provided assessments of reading skills (responses were spoken and/or signed), and the Word Attack subtest from the Woodcock Reading Mastery Test provided-grade-equivalent scores for phonic and structural analysis skills (responses were spoken). Phonological coding skills were assessed using the RHYME rhyme recognition task in which cards are sorted into pairs that “sound alike” and “do not sound alike.” A lexical decision task was included in which half the nonwords were homophonic to a corresponding real word (e.g., word, werd) and half were nonhomophonic.

Geers found that better reading scores were associated with age (9-year-olds better than 8-year-olds), age of hearing loss onset (better among children who became deaf later), and higher nonverbal intelligence. Among the implant-related characteristics, duration of SPEAK software use, number of active electrodes, and dynamic range were all associated with higher reading scores. In contrast to most findings concerning hearing and language abilities (e.g., Archbold, Nikolopoulos, & O’Donoghue, 2006; Connor, Hieber, Arts, & Zwolan, 2000; see Marschark & Spencer, 2006), age of implantation was not associated with better reading scores (i.e., younger is normally better). Variables related to speech therapy, parent involvement, and private versus public schooling also were unrelated to reading skill, but children who were in mainstream programs and used spoken language were found to be better readers. Geers concluded that an emphasis on spoken language is an important educational choice for children who receive their cochlear implants early.

Findings of this sort do not allow assessment of whether it is children’s postimplantation language orientations or their early (preimplant) language skills that are responsible for their reading success because the children who performed better had later hearing loss onsets and hence longer (pre–hearing loss) exposure to spoken language. A similar caveat could be argued with regard to Geers’s finding that enrollment in mainstream settings was associated with higher reading scores relative to enrollment in separate programs for deaf children, because random assignment to different school placements is not feasible for such studies (Marschark, 2007, pp. 49–52).

Geers (2003) reported word reading and comprehension data for 181 children who were 8–9 years old, noting that over half scored within the average range for their age relative to normative data for hearing children. Reading competence was positively associated with nonverbal intelligence, family socioeconomic status, language skills, and early auditory experience (i.e., later onset hearing loss and implantation). Geers (2004) also reported testing 181 children (presumably the same as those in the 2003 study) and presented data from 133 children with congenital hearing losses and performance IQ scores of 80 or greater. Another sample of 39 children with deafness acquired by age 3 years was also described. Neither age of implantation nor duration of implant use was found to be related to reading comprehension, findings replicated by Willstedt-Svensson, Sahlen, Maki-Torkko, Lyxell, & Ibertsson (2005; cf. Sherman & Cruse, 2004).

Although it is sometimes assumed that earlier implantation per se leads to better outcomes, the Geers studies point out that this association is mediated by both the extent of auditory experience prior to hearing loss and the length of time between hearing loss and implantation, factors frequently acknowledged but rarely examined in relevant studies. Her results indicate that later onset hearing losses (and thus later implantations) are associated with better reading ability, presumably because those children have greater language experience to support their learning to read. Alternatively, the failure to find an inverse relation between reading and age of implantation might simply indicate that the link between language and reading is an indirect one (see Connor & Zwolan, 2004, below).

In a postscript to the previous three studies, Geers (2005) reported an examination of reading levels of each child in a subsample of twenty-six 8– to 9-year-old children with implants, also involved in the summer camp testing program. Follow-up data were obtained when the children were in high school. Those data revealed that although, as a group, the children were reading on grade level (mean grade level 3.4) when they were 8–9 years old (in Grades 3–4), by the time they were 15–16 years old, they were an
average of almost 2 years behind grade level. Those 9th and 10th graders had a mean grade level of 7.7, with 10 of 26 reading at or above grade level 9.5. Geers reported that 16 of the students (61% of the sample) scored within the average range for hearing-age mates, but the data from the individual students indicated that impressive early reading achievement for children with implants does not necessarily maintain over time. This may be a result of the fact that around the fourth grade (in the United States), we stop teaching children to read and expect that they will read to learn. Such findings thus may reflect a lack of explicit instruction and/or the greater vocabulary demands of books for older children (Wauters, Tellings, van Bon, & van Haaften, 2003) rather than anything specific to language development per se. Nevertheless, such data are a reminder that cochlear implants are helpful for many if not most deaf children learning to read, even if they do not completely level the playing field with hearing-age mates. The language and cognitive abilities underlying reading are complex, and the link between language and reading is not necessarily a direct or simple one.

Relations of Language, Reading Achievement, and Cochlear Implantation

The large-scale studies by Geers provided evidence that greater exposure to spoken language communication during the school years was associated with enhanced reading abilities, but her analyses indicated that other factors may have been more important. Connor and Zwolan (2004) examined the possibility of an indirect link between language and reading abilities in a study involving 91 children using cochlear implants. Their pool was reported to have an average age of 11 years, and all had used their implants for at least 4 years at the time of evaluation. Ten children received their implants prior to age 3 years, 40 at age 5 years or younger (14 between 3 and 4 years), and 51 after age 5 years (32 prior to 9 years, and 19 between 11 and 14 years of age). All attended regular local schools and used either spoken language or total communication in educational settings. Connor and Zwolan assessed preimplant vocabulary using the Picture Vocabulary test of the Woodcock–Johnson Test of Cognitive Ability and the Expressive One-Word Picture Vocabulary Test. After implantation, reading comprehension was evaluated using the Passage Comprehension subtest of the Woodcock Reading Mastery Test—Revised. Children gave their answers using signed and/or spoken language.

Connor and Zwolan (2004) did not report the reading levels of the children involved in their study, so there is no way to know how they compared with those of deaf children without implants or hearing-age mates. In contrast to the results obtained by Geers (2004), they found that earlier implantation was associated with higher reading comprehension scores, and communication method did not directly affect reading comprehension scores when other variables were controlled. Length of implant use was negatively related to reading comprehension, suggesting the attenuation of implant-related facilitation in reading among older children (Ibertsson, Vass, Årnason, Sahlen, & Lyxell, 2006). Similar results can be found in data reported by Johnson and Goswami (2005) and Geers (2005).

Johnson and Goswami (2005) examined the phonological awareness skills of children who had received cochlear implants prior to age 3.2 years, children who had received implants after age 3.8 years, and comparison groups of deaf children who used hearing aids and reading age-matched hearing children. Tasks examined awareness of rhyme and phonemes as well as speech-reading (Test of Adult Speechreading word subtest). Vocabulary development, rhyme awareness, and speech-reading all were positively related to reading ability, but there were no differences among the three groups of deaf children in either reading ability or phonological awareness. Assuming that the children with hearing aids had hearing losses comparable to the children with cochlear implants (not reported), these results suggest that there are alternative routes to reading other than or in addition to skilled phonological processing (Connor & Zwolan, 2004; Leybaert, 1993), at least for children who receive their implants early. The generality and reliability of such results, however, remain to be determined.

Archbold et al. (2006) examined the effect of age of implantation on reading ability in a study including 105 children who received cochlear implants between the ages of 1.3 years and 6.9 years ($M = 4.1$ years). Five
years after implantation, the children had achieved reading levels ranging from 4.3 years below grade level to 2.6 years above grade level ($M = 0.9$ year delay). Conducting another follow-up study 7 years after implantation, Archbold et al. found an overall mean reading delay of 2.2 years. More importantly, there were significant effects of age of implantation at both points of test. At the 7-year follow-up, 100% of the children implanted between 6 and 7 years of age were reading more than 1 year below grade level. Among those implanted between 4 and 5 years, 81% were reading more than 1 year below grade level. Only 44% of children implanted between 1 and 3 years of age were reading more than 1 year below grade level, however, whereas 46% were reading within 1 year of grade level and 10% were reading more than 1 year ahead of grade level. Archbold et al. emphasized the importance of early implantation to reading achievement, but, like (Geers, 2004), also pointed out that cochlear implants do not guarantee reading success.2

Moog (2002) conducted a study involving 17 children with cochlear implants between 5 and 11 years of age who attended an intensive oral program that provided focused instruction in reading. The children had been implanted between 2.4 and 7.7 years ($M = 4.2$ years) and were tested when they were between 5.8 and 11.8 years of age. Fifteen of the children had prelingual hearing losses (12 congenital). The children were administered the Phonetically Balanced-Kindergarten word lists to test speech perception, the Picture Speech Intelligibility Evaluation to test speech intelligibility, the Peabody Picture Vocabulary Test (third edition), as a measure of receptive vocabulary, and the Expressive One-Word Picture Vocabulary Test as a measure of expressive vocabulary. They also were tested using the Clinical Evaluation of Language Fundamentals (CELF-3) to examine receptive and expressive language skills and the Gates MacGinitie Reading Test (third edition) and the SAT9 to assess reading. Moog reported neither any statistical analyses, comparisons with other groups of children, nor any relations between language and reading. The only reference to reading achievement was that more than 70% of the students (apparently, 12 of the 17) scored within the average range for their age. Moog concluded that “These data demonstrate what is possible for deaf children who benefit from a combination of a cochlear implant and a highly focused oral education program” (p. 138).

The Iowa Studies

Although clinicians usually emphasize the importance of spoken language skills for children with cochlear implants, several studies from a research group at the University of Iowa have evaluated the reading abilities and academic achievement of children with cochlear implants who were exposed to both sign language and spoken language. Most of those children have received support from sign language interpreters throughout their school years and appear to use sign and speech (not necessarily together) in various contexts. Spencer, Tomblin, and Gantz (1997), for example, investigated the reading skills of 40 such children who had prelingual, profound hearing losses. At the time of testing, the children were aged 6–17 years ($M = 11.17$ years), had received their implants between the ages of 2 and 13 years (cf. Archbold et al., 2006), and had from 2 to 9 years experience with their implants ($M = 5.3$ years). Note that this contrasts with the Geers studies, insofar as the children all had prelingual hearing losses but did not necessarily have their implants prior to age 8 years.

Using the Woodcock Reading Mastery Test—Revised, Spencer et al. (1997) found the children to have a mean grade-level reading score of 4.13, although variability was quite high ($SD = 3.65$) undoubtedly due to the large age range. The 28 children who were in grades 4–12 were reported to have achieved a mean grade-level reading score of 5.15 ($SD = 3.9$). Approximately 25% of the children were reading at or above their grade levels and almost 20% within 8 months of their grade levels, but another 25% were reading at a level 30 months or more below grade level. Spencer et al. reported that 54% of the children between Grades 4 and 12 were reading above the fourth grade level. This compares with normative data from the SAT9, indicating that approximately 50% of deaf 18-year-olds read below the fourth grade level and 50% read above that level (Traxler, 2000).3 Spencer et al. did not report on relations among age of implantation, duration of implant use, language skills, and reading ability.
Tomblin, Spencer, and Gantz (2000) explored language development in a group of 17 children who had prelingual, profound bilateral hearing losses and received cochlear implants between 2.6 and 10 years of age. Reading acquisition was examined in a group of 30 children including “most of the children” (p. 302) who participated in the language study. Those children also had prelingual, profound bilateral hearing losses and received cochlear implants between 2.6 and 14 years of age. At the time of testing, children in the language study ranged in age from 8.5 to 18.4 years ($M = 12.8$ years) and had experience with their implants ranging from 3 to 11 years ($M = 7.1$ years). The Woodcock Reading Mastery Test—Revised and three language measures from the CELF were administered, with the reading evaluation administered to the group of 30 children twice, 1 year apart. At the time of the first evaluation (mean age 11 years, average grade level mid-fifth grade), the mean grade-level-equivalent reading score was mid-third grade. At the time of the second evaluation (mean age 12 years, average grade level mid-sixth grade), the mean reading level was mid-fifth grade, a 2-year improvement. In particular, the students who were nearing the end of high school were found to be “reaching average to above average reading levels, whereas the children in early grades [were] well below average” (p. 303, cf. Geers, 2005). Tomblin et al. (2000) concluded that there is a causal relationship between spoken language and reading, but explicit relations between their language data and reading data were not examined.

A study by Spencer, Barker, and Tomblin (2003) involved another small sample: 16 children with an average age of 9.8 years. They had received their implants at an average age of 3.9 years and had an average length of experience with their implants of 5.9 years. All were enrolled in public school classrooms with sign language interpreting support and were reported to use simultaneous communication. The study included a comparison group of 16 hearing children with a similar mean age. Spencer et al. (2003) used the same reading and language assessments as Tomblin et al. (2000) and also elicited writing samples. Reading comprehension scores of the children with implants were significantly below those of the hearing children, but only by about 10% (99.5 vs. 90.1).

Grade-equivalent scores indicated the children with cochlear implants to be reading at an average grade level of 3.3 years and the hearing children at 3.8 years. Note that although individual grade levels were not indicated, the reported average age would have put these children at around fourth grade. Ten of the 16 children with implants were reported to be within 1 $SD$ of the average standard score according to available norms, and only two fell below 1.5 $SD$s of the average standard score. The deaf children also lagged behind their hearing peers in writing productivity, which was reliably correlated with language scores for the deaf but not the hearing children. Given the relatively better reading skills of the children with implants relative to typical findings with deaf children (e.g., Traxler, 2000), Spencer et al. concluded that literacy skills among children with cochlear implants are associated with gains in English language competence made possible by their implants.

Spencer, Gantz, and Knutson (2004) obtained similar results in a study involving 27 children consecutively implanted at a single center. All had prelingual hearing losses and received their implants between 2.4 and 12.7 years of age ($M = 6.4$ years). At the time of testing, they had between 3 and 14 years experience with their implants ($M = 9.9$ years). The children were tested subsequently either when they were in the 10th grade or at least 16 years of age. Of the 27 participants, 24 reported at least 7 years of consistent implant use, where “consistent” was defined as eight or more waking hours. Seven of the participants wore their implants only in school or at work. Another 10 students apparently discontinued use of their implants either during the first 3 years after implantation (three) or later (seven). Admittedly, there was a large age range in this study, but it also involved consecutively implanted children, inclusion of inconsistent as well as consistent implant users, and a relatively long period of implant use for most children. Taken together, these factors make it an important investigation of the long-term effects of cochlear implantation on reading (see Beadle et al., 2005) and one likely having greater validity than many studies.

The inclusion of a number of late-implanted children suggests that significant reading delays would be likely in the Spencer et al. (2004) study, at least on the
basis of the Archbold et al. (2006) findings. In fact, scores on the Woodcock Reading Mastery Test—Revised (with a standard score of 100 for hearing children) indicated that the entire group of children with implants had a mean score of 89 ($SD = 17$) and those who were consistent users of their implants had a mean score of 92 ($SD = 17$). The inconsistent implant users had a mean score of 77 ($SD = 7$). Thus, those students who consistently used their cochlear implants generally were reading on par with hearing age-mates, and the group as a whole was well within normal limits (expected $M = 100$, $SD = 15$). The only apparent difference between this study and that of Archbold et al., aside from the small and diverse sample, was the fact that all the students in the Spencer et al. study used both sign language and spoken language, whereas most of those in the later study apparently used spoken language in school.\(^5\)

Reading Related to Other Aspects of Achievement

Three additional studies are relevant to the discussion of reading abilities of children with cochlear implants. Although each is quite different, they have in common a rather broad perspective on literacy skills in this population. Vermeulen, van Bon, Schreuder, Knoors, and Snik (2007) examined reading comprehension and word recognition as separate indicators of reading ability of children in The Netherlands. The study involved a comparison of 50 students with implants (aged 7–22 years) with data collected by Wauters, van Bon, and Tellings (2006) from 504 deaf students with hearing aids and a comparison group of hearing students. The mean age of hearing loss onset was 1.1 years ($SD = 1.6$ years), and the mean age of implantation was 6.2 years ($SD = 2.3$ years). All the children with implants had a minimum of 3 years implant experience, but there was a mean duration of auditory deprivation prior to implantation of 5.1 years ($SD = 2.8$ years). Forty-five of the 50 had prelingual hearing losses, most of them acquired. Vermeulen et al. (2007) found that educational placement prior to implantation was unrelated to reading scores (cf. Geers, 2002). Reading comprehension among the children with implants significantly exceeded that of children with hearing aids, but still lagged significantly behind hearing peers. Implants were associated with an advantage in word recognition relative to hearing aids only among secondary school students, not primary school students. Vermeulen et al. (2007) noted, however, that the participants in their study had been implanted relatively late (between 2 and 12 years, with a mean of 6.2 years), a difficulty also inherent in the Iowa studies.

Thoutenhoofd (2006) conducted a study involving 152 school-aged deaf students with cochlear implants drawn from the population of 1,752 deaf students in Scotland. Children ranged in age from 5 to 12 years ($M = 8$ years), were an average age of 3 years old when they received their cochlear implants, and had an average of 4 years experience with their implants. Thoutenhoofd examined National Test assessments in several academic subjects (see below). With regard to the reading scores, he found that older students with implants were farther behind in their reading skills (for their chronological age) compared to younger students, a finding similar to that reported by Geers (2005). Students aged 11–13 years lagged behind their hearing peers in reading scores by approximately 3 years, whereas students aged 15–17 lagged by 4–5 years. Analyses controlling for age of implantation were not conducted, so it is unclear whether such results reflect a real widening gap in literacy skills for implanted children over the school years or a confound due to the fact that older children may have received their implants after a longer period of auditory deprivation (Connor & Zwolan, 2004).

Crosson and Geers (2001) examined the narrative abilities of 87 children aged 8–9 years who had used their implants for at least 4 years, relative to 28 hearing children. Scores on the Reading Comprehension subtest of the Peabody Individual Achievement Test also were reported. Stories were prompted using an eight-picture sequence, and children’s productions were scored on the basis of several discourse-related features. Children with better speech reception skills were found to produce better narratives, a finding consistent with the hypothesis that narrative abilities are acquired largely through incidental learning. Narrative skills also were related to reading. The children in grades 3–4 obtained an average reading level of grade 2.5. Scores were reported as ranging from grade level 0.1 to 8.3, but the $SD$ was only 0.15, indicating that
most of the children were reading at or below grade level. Using a discourse scoring system that emphasized use of conjunctions and particular referents, Crosson and Geers found that children with profound hearing losses were “deficient” in their narrative skills. That result contrasts with conclusions from research involving story grammars, in which deaf children aged 7–15 years who sign have been found to be comparable to hearing age-mates in their narrative abilities even without picture prompts (e.g., Marschark, Mouradian, & Halas, 1994). Nevertheless, the Crosson and Geers findings are consistent with the earlier results in indicating that children with better language production skills are also better narrators.

In summary, the above research indicates that children with implants frequently read better than deaf peers who utilize hearing aids, even if they lag behind hearing age-mates. The link between age of implantation and length of implant use is rather inconsistent, however, either reflecting the considerable heterogeneity of deaf children relative to hearing children (Marschark, 2007) or indicating methodological confounds. For example, children with later hearing losses, who thus likely have greater preimplant language skills, tend to show better reading achievement, but this confound is not addressed in most relevant studies. There are also several studies indicating that children with implants who have access to both spoken and sign language throughout their school years show higher levels of reading achievement. Those investigations have involved samples quite diverse with regard to age and age of implantation, however, and whether the findings reflect a contribution of simultaneous communication per se, the benefit of early access to language, or enhanced access in the classroom through the availability of both speech and sign remains to be determined.

Taken together, all the results discussed thus far emphasize a positive link between early expressive language skills and later language-related achievements by children with cochlear implants, whatever the modality of their preimplant communication (Spencer & Marschark, 2003; Yoshinaga-Itano, 2006). Some caution is needed in this regard because children who have congenital or early-onset hearing losses also may be implanted earlier (and reported in the literature earlier), but they also will have lesser experience with their cochlear implants (see note 2). Further, studies by Geers (2005) and Thoutenhoofd (2006) indicate that grade-level reading abilities in younger children do not necessarily maintain through secondary school. Such findings may reflect the fact that deaf children with implants do not have hearing, language, and speech skills fully comparable to hearing peers, even if they fall into the normal range (Yoshinaga-Itano, 2006). Most children with cochlear implants function like hard-of-hearing children, at best, and hence likely are at a disadvantage with regard to phonological processing and phonemic awareness as well as incidental learning from auditory information. Those disadvantages would be significantly less than what is experienced by peers without implants and comparable hearing losses, accounting for differences reported between children with implants and those with hearing aids, but they appear nonetheless sufficient to have specific impact on reading ability. Another possibility is that early gains in reading, at least at the group level, decline because some students opt out of speech services during their teen years, services that provided them with early advantages. Those services also may have been more intensive during younger years, when they were learning to read (Wauters et al., 2003), and thus contributed to early reading success.

Before drawing strong conclusions about a link between the quality of auditory input and reading among children with cochlear implants, it is important to look at academic achievement more broadly. To the extent that cochlear implants fall short of providing deaf children with access to classroom information that is fully comparable to that of hearing peers, the pattern of results observed in assessments of reading ability may be more general than is supposed by those who focus on sound-level foundations of reading. This situation is akin to the seeming obsession of educators and investigators with deaf children’s literacy skills, when challenges are observed across essentially all parts of the curriculum (Jensema & Trybus, 1978; Marschark, Lang, & Albertini, 2002). It is only when we understand the whole functioning of deaf children in social, language, and academic domains that we will be able to fully support their needs and take advantage of their strengths.
Cochlear Implants and Academic Achievement of Deaf Children

As in the literature concerning the development of literacy skills by children with implants, it is not difficult to find implicit if not explicit suggestions that those children should demonstrate greater academic achievement than deaf children who rely on hearing aids or do not use assistive listening devices. Some of those assertions likely are based on the assumption that implants will provide greater access to information in the classroom, but few if any studies have examined deaf children’s implant-aided perception of spoken language in real-world settings (O’Donoghue, 2006). There also appear to be assumptions that because implants facilitate literacy skills, academic achievement necessarily will be enhanced. Some evidence with regard to the effects of cochlear implants on academic achievement is available, but there appear to be several “red herrings” as well.

Results obtained by Summerfield (2004) are a case in point. Several secondary sources have reported that Summerfield found children with implants to demonstrate superior academic achievement relative to children with hearing aids (e.g., Archbold, 2005). Although Figure 3 of that report is labeled “Children with implants achieve more,” the data actually represent results from a survey of teachers who “estimated the abilities of children in reading, writing, and number work” (p. 3). The graph indicates that teachers rated deaf children without implants as showing steep declines in academic achievement as a function of degree of hearing loss, whereas children with implants were rated as performing at uniformly high levels of academic achievement across a wide range of hearing losses. Again, however, these were teachers’ opinions, not actual measures of academic performance, and it is unclear how much exposure the teachers had to children with cochlear implants.

O’Donoghue (2006) and Beadle et al. (2005) criticized prior studies looking at achievement following cochlear implantation, as well as hearing, speech, and language studies more generally, for lack of careful experimental methods. They pointed out that the results of many studies are tainted by (a) the exclusion of low performers and children who have discontinued regular use of their implants (i.e., selection bias), (b) not including individual data on all children, (c) bias in testing protocols (i.e., over-reliance on laboratory tasks unrelated to real-life situations), (d) inadequate experimental follow-up, and (e) poor or at least limited experimental designs (i.e., lack of prospective and longitudinal studies). Beadle et al. therefore designed a study that was both prospective and longitudinal, involving a group of 30 consecutively implanted children. They followed all members of the group over a 10-year period after implantation with regard to “device use and function, speech perception and speech intelligibility outcomes, and current academic or occupational status” (p. 1152). The children in this unselected sample were all profoundly deaf prior to implantation at 2.5–11 years of age ($M = 5.2$ years) and were implanted in the same center over a 4-year period. The only child excluded from the study was one whose implant was removed due to persistent middle ear infections and pain whenever the implant was stimulated. At the time of study, all the children had 10–14 years of implant experience.

Although many of the findings from the Beadle et al. (2005) study are beyond the scope of this article, it is interesting to note that after 10 years of implant experience, 26 (87%) of the 30 participants reported that they always wore their implant and gained considerable benefit from it. Sixty percent (18 of 30 participants) were able to use the telephone with a familiar speaker. Eight (26.7%) of the children, however, experienced device failures (and one child had two failures) and had to be reimplanted.

With regard to academic attainment, 19 participants were under the age of 16 years at the time of testing and attended academic secondary educational programs. Six of those were in schools for the deaf, seven in units attached to regular local schools, and six in regular local schools with support services ranging from a note-taker to an occasional visit from an itinerant teacher of the deaf. Seven of the secondary students were in programs where they used total communication and code switched regularly between speaking and signing, depending on their communication partners (see note 5); the other 12 used primarily spoken communication in the classroom. Ten of the 30 participants were attending college or university at the
time of study, enrolled in a variety of academic and vocational programs, and four others were completing additional academic courses with the goal of entering college or specific employment. Half of them used spoken communication in academic settings, yielding 17 of the 30 original participants who exclusively used spoken language in academic settings. Specific levels of academic achievement were not reported, but with 29 of 30 students enrolled in secondary and postsecondary educational programs (one stayed home full-time with her two children), it appears that this group could be considered academically successful.

More specific evidence on academic achievement is available from two published sources. One is the study by Spencer et al. (2004) described above with regard to literacy. They also examined academic achievement using the science, social studies, and humanities subtests of the Woodcock–Johnson Tests of Achievement. As was the case for reading, Spencer et al. found that the “CI participants” (apparently those students who were consistent users of cochlear implants) performed comparably to hearing age-mates, achieving an overall mean score of 103.88 (SD = 19.93), where the expected score for hearing children would be 100. Performance of students who did not use their implants was not reported. Spencer et al. also noted that 16 of the participants in their study had already reached the age of 18 years. Seventy-five percent of those young adults (12) were attending postsecondary institutions, two were homemakers, and two did not report their current status. Once again, this is a group of individuals who presumably would be considered academically successful.

The Spencer et al. (2004) study also is noteworthy because it is the only one available in which deaf children with implants have been found to be performing at a level fully equivalent to hearing age-mates in academic performance, and the students had utilized both sign and speech during the school years. There were only 27 children in the study with a fairly large age range, but the fact that the sample consisted of consecutively implanted children who were both inconsistent and consistent implant users gives considerable confidence in the validity of the results. The findings also emphasize that use of sign language with implants should not be anathema, although more research clearly is needed to clarify the effects on the academic achievement of spoken and sign language at different ages.

Thoutenhoofd’s (2006) study of school-aged deaf students in Scotland, also described in the previous section, included evaluation of academic achievement in mathematics and writing as well as reading. He found that differences between deaf and hearing children in academic achievement were attenuated by cochlear implants, as students with profound hearing losses and implants functioned more like hearing aid users who had moderate losses in mathematics and like students with moderate to severe losses in writing as well as reading. Most deaf students with cochlear implants still performed below the national average across academic areas, however. Thoutenhoofd did not examine relations between language and achievement, but he reported that 79% of the students were exposed only to spoken English at home and 46% were exposed only to spoken English at school.

Interestingly, Thoutenhoofd examined the frequency with which children moved into and out of separate programs for deaf children. In contrast to the common assumption that children who receive cochlear implants are likely to move from separate programs into mainstream classrooms (M. Svirsky, personal communication, November 1, 2006), he found no such migration. Most of the students with implants at the outset of his study were in mainstream classrooms and stayed there. Of the 60 students originally in mainstream schools, 19 moved out of those schools into special placements intended for deaf students. In contrast, only six students moved from special placements to mainstream settings. Data of this sort are not available from most other studies (but see Vermeulen et al., 2007), so the question of the effects of cochlear implants on educational placement for deaf students with implants remains uncertain. It has been argued that cochlear implants and mainstream placements may be more economical than hearing aids and separate school placements for deaf children (e.g., Francis, Koch, Wyatt, & Niparko, 1999; O’Neill, O’Donoghue, Archbold, & Normand, 2000), but the issue of academic success for children with various characteristics remains to be empirically explored.
Discussion

Archbold (2005, p. 54) suggested that “cochlear implants may work too well.” She noted that children with implants may appear to hearing teachers as having no hearing-related difficulties, and thus they also may appear not to require any support services in the classroom. “However, in typical noisy educational settings with increasingly demanding curricula, the child needs sensitive support, and monitoring of the functioning of this complex technical system they wear. At secondary or high school level, the implanted deaf child may have excellent intelligibility of speech but lack the sophisticated language to deal with complex curricula, particularly in noise and with changing teachers.” Indeed, it appears a tacit assumption in the field—and certainly one taken home by many parents of deaf children—that the enhanced language skills typical of most deaf children who receive cochlear implants will allow them to function at the level of hearing peers in regular school classrooms.

The literature review above indicates that even if children with cochlear implants frequently surpass deaf age-mates who have hearing aids and similar hearing losses, implants do not guarantee reading and other academic skills comparable to hearing age-mates. Although young deaf children in some studies have been reported to be reading at age-appropriate grade levels, preliminary evidence suggests that there is later divergence, as those advantages are not necessarily maintained by all children, even among those who received their implants relatively early (e.g., Archbold et al., 2006; Geers, 2005; Ibertsson et al., 2006; Johnson & Goswami, 2005). “Early” in most studies, however, refers to ages 1–3 years, and it remains to be seen whether similar findings are obtained with children who are implanted within the first year. Given the findings thus far, however, one should not assume that academic differences between deaf children and their hearing peers will disappear if the former receive cochlear implants.

This caveat follows from several factors underlying learning by children with significant hearing losses (Marschark et al., 2002). Most obviously, children with implants do not have hearing, speech, or language skills that are equivalent to those of hearing peers, and thus, they are likely to miss some amount of information in the classroom. A similar argument would apply to informal learning situations (both explicit and incidental) prior to the school years as well as during them. It may be that the advantage seen in studies by Tomblin, Spencer, and their colleagues for children who use sign language and speech in school with support from sign language interpreters is a consequence of those children having greater access to classroom discourse with two modes of communication rather than one. Children involved in the Archbold et al. (2006) studies also evidence considerable sign language skill, although that variable apparently has not been explored in their studies. Studies by Geers also include children with some amount of sign language skill, because descriptions of the methodologies report that children respond in spoken language and/or sign language, but again, that variable has not been specifically analyzed. Additional studies are needed in order to determine how the link between language modality and reading/achievement might interact with age at implantation, language skills prior to hearing loss, and postimplant fluencies in both signed and spoken language.

Research Needs Better Methodological Controls

Control for language fluencies before and after hearing loss and before and after cochlear implantation is one of the weaknesses observed in the reviewed literature. An advantage in reading ability for children who received their implants later was clearly evident, but only in cases where later implantation apparently entailed later hearing losses. An advantage for children who received their implants earlier was observed when it entailed earlier habilitation for congenital and early-onset hearing losses. Similarly, although some of the studies described above took into account pre- and postimplantation hearing losses in examining reading and academic achievement, most studies analyze language and achievement separately without controlling for language fluencies. Consideration of prior world and vocabulary knowledge is almost nonexistent (cf. Vermeulen et al., 2007), as is examination of preimplantation phonemic awareness or the phonological skills. Results from reading readiness tests thus would be interesting to include in future studies.
Such criticisms are not meant to fault particular studies but are intended as a call to recognize that there are considerable theoretical, practical, and social-emotional consequences of research that frequently only address part of the cochlear implantation story. Studies that lack comparison groups of children who use hearing aids (or not) and have hearing losses comparable to the children with cochlear implants typically refer to standardized norms for hearing children, but there appears to be little effort to ensure that the assumptions underlying those norms (e.g., comparable educational backgrounds, first language fluency) are met. Factors such as socioeconomic status, parental hearing status, early intervention experience, and others known to affect the development of deaf children are largely ignored. Several investigators have emphasized the importance of educational placement involving spoken language after implantation, but it is rare that information is provided as to whether those children had better spoken language skills prior to implantation, thus making them better candidates in the first place. Use of consecutively implanted experimental samples not only provides some remedy for such potential confounds but also creates greater variability due to the greater age ranges typically involved.

Beadle et al. (2005) raised the methodological concern that most studies of children who have received cochlear implants have included only consistent implant users. As a result, reported results of the beneficial effects of pediatric implants likely are somewhat inflated (O'Donoghue, 2006). Certainly, there is likely to be difficulty in contacting and recruiting the research participation of individuals who have discontinued use of their implants for indeterminate causes, sometimes with strong social-emotional consequences. Nonetheless, Beadle et al. and O'Donoghue have argued eloquently from within the cochlear implant professional community that more accurate information concerning implantation outcomes will only benefit the field.

Language, Learning, and Cochlear Implants

Claims that utilization of sign language might prevent children from fully utilizing the potential of the cochlear implants or might facilitate academic achievement remain to be validated. Clearly, the purpose of cochlear implantation is to improve hearing, and the expectation is that speech and language will not be far behind. (Issues of socialization, emotional development, and cognitive growth are beyond the scope of this review and are just now receiving empirical attention.) The threshold for the amount of auditory/spoken language exposure necessary in order for children to optimally benefit from a cochlear implant remains to be determined (Spencer & Marschark, 2003). Although there still has not yet been any demonstration that visual forms of communication will impede development of oral-aural forms of communication among children with cochlear implants, there nonetheless is a strong propensity in the field for emphasizing auditory information over potential sources of visual information for such children.

Research to date has provided strong evidence that pediatric cochlear implantation can provide many deaf children with significant advantages in reading and other academic domains. The extent to which these advantages stem directly from improvement in auditory reception, from enhanced ability to engage in face-to-face language interactions with a variety of individuals, and/or from indirect sources such as greater incidental learning and cognitive growth is unclear. Rather than assuming that achievement necessarily will follow enhanced hearing and language skills, it is essential that we determine which factors support development for different children in different academic placements and family settings. We cannot assume that simply because deaf children with cochlear implants are in mainstream classrooms, they learn just like hearing children. Nor can we assume that when children with implants are in separate classrooms, they learn just like other deaf children. Only when we fully understand how children with implants think and learn will we be able to adjust our instructional methods to match both their strengths and their needs.

Notes

1. Some of the studies reviewed here also were lacking important information such as age of implantation, age of hearing loss, and degree of hearing loss. When relevant information was provided by the original authors, it is included here, but see Beadle et al. (2005) for a discussion of methodological issues.
2. S. M. Archbold (personal communication, January 19, 2007) pointed out that although the effect of age of implantation in their 2006 study was strong, the children implanted early were still relatively young when retested. She suggested that longer term follow-ups will be more informative because more complex skills will be evaluated.

3. Information on the use of cochlear implants is not included in the Traxler (2000) normative SAT9 data.

4. For reasons that are unclear, the numbers reported by Spencer et al. (2004) do not calculate as expected. For example, 71% of a group of 24 individuals were reported to be “consistent users to date,” yielding 17.04 consistent users (p. 1580).

5. One of the authors attended a meeting attended by children involved in the Archbold et al. (2006) and Beadle et al. (2005) studies and was impressed by their code-switching abilities, involving “voice-off” British Sign Language with peers and intelligible spoken English with their parents.

6. The reference cited here and elsewhere as Summerfield (2004) describes his keynote address at the National Cochlear Implant Users Association (United Kingdom). However, the article appears to summarize that presentation rather than having been written by Summerfield.

References


Received December 21, 2006; revisions received March 13, 2007; accepted March 14, 2007.